DOCUMENT RESUME

ED 204 267 SP 017 961

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TITLE Creating Cognitive Dissonance Between Students' Preconceptions To Encourage Individual Cognitive Accommodation and a Group Cooperative Construction of a Scientific Model.
PUB DATE Apr 81
NOTE 28p.: Paper presented at the Annual Convention of the American Educational Research Association (Los Angeles, CA, April, 1981).

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Creative Thinking: *Discovery Learning: *Discussion (Teaching Technique): Elementary Secondary Education: *Intellectual Development: *Questioning Techniques: Science Education: Student Characteristics: Student Motivation: *Teacher Guidance: Teaching Methods
IDENTIFIERS *Cognitive Dissonance

ABSTRACT

Students' preconceptions (also called misconceptions) interfere with desired learning and resist attempts to eradicate them. By applying previous findings about misconceptions regarding the particle model for gases, a new approach was designed for teaching the subject. A "critical situation" was treated in which students in sixth and seventh grade classes were encouraged to develop individual answers to a hypothetical question. The teacher's role was to present the students' reasoning and to encourage discussion. Students engaged in intensive discussions, with the teacher directing the lessons by asking leading questions. The students became personally involved in the debate and in supporting one of the possible answers. By presenting examples, the teacher was able to lead the class toward a consensus. Cognitive dissonance in a group situation was induced, and a cooperative construction of the scientific model was achieved. The students' conceptual change was shown by their increased awareness of alternative frameworks, and by their engagement in personally meaningful discussion about competitive hypothetical models. (Authors/PG)

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Creating Cognitive Dissonance Between Students' Preconceptions To Encourage Individual Cognitive Accommodation and a Group Cooperative Construction of a Scientific Model

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Paper presented at the AERA Annual Convention
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April, 1981

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Introduction

In the area of science education there has been a growing number of reported studies which tried to diagnose cognitive difficulties and barriers that students experience in studying certain science subjects. (i.e., Archenhold et al, 1980; Champagne, et. al., 1980; Driver and Easley, 1978; Clement, 1979, 1981; Erickson, 1980; Hawkins, 1978; Johnstone, 1980; Norman and Clement, 1981; Novick and Nussbaum, 1978, 1981; Posner, et al 1981; Vienott, 1979). Almost all of these proposed that student's preconceptions may play a crucial interfering role in learning science. Leading figures in cognitive psychology, from the Gestalt psychology through Piaget (1964) and to modern cognitive psychologists like Niesser (1976) and Norman (1979), have long maintined that the internalization (the very perception and interpretation) of new information by a person is a function of his existing cognitive structures. Ausubel (et. al., 1978), who has concentrated on cognitive prcesses in school learning, emphasizes that meaningful learning of new information is mostly a process of a 'subsumption' of the new by the relevant set of concepts already held by the learner. The conclusions of the aforementioned studies and the essentials of the leading theories of cognitive psychology seem, therefore, to be mutually supportive.

Many preconceptions that students hold include some 'naive' metaphysical assumptions about the nature of the physical world which are incompatible with the metaphysical foundation of current scientific conceptions. When one recognizes that, it become clear why Ausubel (1978) states that:

> "...Unlearning of preconceptions might prove to be the most determinative single factor in the acquisition and retention of subject-matter knowledge..."
>
> "...These preconceptions are amazingly tenacious and resistant to extinction."

When a student retains and continues to use his preconception to interprete classroom information, he is likely to give it meaning which differs from or even conflicts with the meaning intended by his teacher. It is possible that the learner is not even aware of this gap and that he is perfectly satisfied with his own interpretation, thinking that such was also his teacher's intention. The teacher too can be totally unaware of how the student has internalized the new information and when he does sense that something is amiss, he will often attribute it to the student's "not understanding" the lesson. We wish to argue that it is not a matter of his "not understanding" but of his "understanding differently" from what was intended. In so doing, he may very well give a rational and even a sophisticated meaning to the new information, which is indeed at variance with the accepted meaning (i.e., Nussbaum, 1979).

In each science discipline it is possible to identify few central conceptions that include some metaphysical assumptions accepted apriori by current science. These central conceptions constitute the foundation and the 'structure' of the specific discipline. Therefore, internalizing these central conceptions is the key to the understanding of the subject-matter of the discipline. These central conceptions are mostly not in consonance with the learner's 'naive' preconceptions. Some examples of such central conceptions with their dissonant respective naive

preconception are the following:

Matter as particlate vs. Matter as Continuous;

Newton's assumptions of mechanics vs. Aristotalian ones;

Heat as one form of energy vs. heat as 'caloric';

Einstein's assumptions about the nature of space and time vs. Newtonian ones;

Statistical models vs. mechanistic models; (in the atomic theory, genetics, etc.)

A spherical earth vs. a flat earth;

Heliocentric cosmology (or even centerless cosmology) vs. a geocentric one;

A mechanistic approach to biology vs. a vitalistic one; etc.

It should be clear, therefore, that it is in the area of internalizing central conceptions of a discipline that the strongest interfering effect of students' preconceptions is to be expected.

Several of the aforementioned researchers adopted the term "accommodaton" from Piaget's theory* (1964) to describe what happens in the student's mind as he modifies his preconceptions (or even replace them by new ones) to reach consonance with the scientific conceptions. The degree of cognitive accommodation demanded from a student in studying science varies with the nature of the studied subject and with the nature of the student's preconceptions. The internalization of central conceptions, naturally, demands a major accommodation on the part of the

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*Though this term is borrowed from the terminology of Piaget's theory, its employment by others, as well as by us throughout this paper, should not imply any commitment to his theory as a whole.

student for the reasons developed above.

The purposes of the present paper are (1) to propose an account of the components of the accommodation process with main emphasis on major accommodations, (2) to propose guidelines for instructional strategy that may encourage the occurance of accommodation, and (3) to demonstrate an application of the above (1) and (2) (the account of the accommodation process and the proposed instructional guidelines) to the teaching of a specific science subject; namely, the introduction of the particle model for gases. This will be done by a presentation of a case study from the classroom.

How to Facilitate Cognitive Accommodation

Cognitive accommodation is not a process which one can schedule, monitor and guarantee. What one can do about this process is to try to characterize it and to look for instructional strategies that may facilitate its occurrence. Various writers, (i.e., Posner, et al. 1981) agree that accommodation necessitates an acknowledgement of the existence of the problem and the inability to solve it by using existent preconceptions. The result of the first step is a feeling of dissatisfaction. If this feeling is strong enough it may build up to a psychological state which Piaget (1964), in the context of cognitive development, named "disequilibrium" and which Festinger (1958) and others, when they studied attitudes and beliefs, called "cognitive dissonance." These psychologists hold that human beings, by their very nature, have the need to reduce dissonance, incongruity or conflict between two cognitions. This need, when spured by dissonance, often leads to some accommodation of

individual conceptions or beliefs. Ausubel (1978) advocated to induce "cognitive dissonance" in learning situations in school setting to arouse motivation and attention and to create the need for accommodation. However, classroom research report only very rarely about the employment of strategies to induce "cognitive dissonance" in students which may lead to a major accommodation of preconceptions about the physical world.

It is desireable that students accommodate their preconceptions as they learn science subjects. Unfortunately, too many writers of textbooks and teachers usually assume that, when central science conceptions are introduced in the classroom, their job is done by simply demonstrating a few "classical" experiments in a simplified form. It seems as if they believe that the very observation or performance of such experiments are sufficient for the learner (by some way of "logical necessity") that the presented scientific conception is indeed "correct". They treat these classical experiments as if their structure serves a critical role in initiatingg conceptual change, independently of the "readiness" of the learner. The various studies cited at the beginning of this paper, and other similar studies show that too often this is not the case.*

Why is the demonstration of such "classical" experiments, per se, not enough to create the desirable accommodations in many students? We

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*Studies in the history of science show that this very popular picture of one ("classical") experiment or phenomenon causing the conceptual change in those great scientist of the last centuries is a false one. Many times phenomena or experiments which are presented today by textbooks as the crucial proof for a theory were not recognized so easily as such by scientists. Only when some "readiness" (whose nature deserves further study) was established in some outstanding scientists, the phenomena was recognized and contributed to the conceptual change. An example, which is relevant to the topic of this paper is the phenomenon known as "Brounian motion." The impression that most junior high school textbooks give is that this phenomena <u>easily</u> prove the particle motion. The fact was that this phenomenon was known to scientists for several decades before it was realized that it may reflect the unseen motion of the particles (Toulmin, 1962).

propose that is is because students read about, observe or even perform those experiments before they are given the chance to recognize the existance and the nature of the problem and before they experience the needed "cognitive dissonance." It is mainly through some state of "cognitive dissonance" that one can gain appreciation for the potential and the value of a rival scientific conception.

The authors are incline to accept, in general terms, the analogy drawn between the cognitive processes which occur in students, as they internalize central scientific conceptions, and the accommodations of the conceptual frameworks which occurrred in the scientists who formulated those conceptions.* This analogy was, probably, drawn first by Piaget (1962) and is favored by many recent researchers, like those referred to in the introduction above. However, we recognize that this analogy is only partial and will always remain so. Students are different from those great scientists of the past in various very important respects. These differences are with respect to: age and intellectual capacity; repertoire of past experience with nature phenomena; previous relevant knowledge; previous knowledge in other areas which might provide analogies and metaphores for interpreting problem situations; the amount of time and effort devoted for studying this area of knowledge in which the specific

*Accommodation of conceptual frameworks are viewed by recent trends in the philosophy of science as the key for the progress of science in historical perspectives (Kuhn, 1970; Toulmin, 1972; Brown, 1977). It has been proposed recently by Novak (1977) that the recent ideas coming from the history and philosophy of science in conjunction with appropriate theories from cognitive psychology (Ausubel, 1978), may offer highly valuable contribution to our understanding of "human understanding," in general, and of school learning, in particular.

problem exists; etc. As a result of their advantages in all of these respects scientists of the past were likely more aware of the essential elements and features of their own (pre)conceptions before they engaged in studying problem phenomena that may have lead them to accommodate their conceptions. On the other hand, students, having the disadvantages in the respects mentioned above, are not aware of the essential elements of the preconceptions which they in fact hold and use.

In our view, the most important step in an instructional strategy for facilitating accommodation should be making every student aware of his own preconceptions. To achieve this purpose, there is a need for some devised situation which will aid in initiating exposure of preconceptions for all students. In a teacher guided discussion which should follow such a situation, various preconceptions that have surfaced will be analyzed and a better self awareness is likely to ensure. In the strategy that we propose and demonstrate, through a case study, we react to this need by creation what we call "a critical situation." A "critical situation" includes a presentation of some phenomenon which invokes the employment of preconception in order to understand it. The "critical situation" should be such that it will be very appealing for the preconception to be explicitly used and thus become exposed. In order for a teacher or

curriculum writer to devise a successful "critical situation" some previous knowledge about possible preconceptions and misconceptins is required. Here is a place where findings of studies like the ones cited above can contribute to the practice of teaching.

In a later step, only after each student has become aware of his/her own preconceptions, a problem situation might be introduced. It is hoped that now the students are ready to realize more deeply the problem situation as such. The role of this problem situation is to create a state of "cognitive dissonance" that might subsequently lead to the expected accommodation.

By way of summary, the following guidelines are proposed for the designing and sequencing of learning activities in science subjects where significant accommodations are expected.

1. Create a "critical situation" which requires students to invoke their preconceptions in order to interpret it. By this way preconceptions will come up to the surface and be exposed.
2. Encourage students to describe verbally and pictorially their alternative frameworks.
3. Assist students in stating their ideas clearly and concisely, thereby making them aware of the elements in their own alternative frameworks.
4. Encourage confrontation in which students debate the pros and cons of the different preconception and increase their awareness and understanding of the differences between

their own conceptual framework and other's alternative ones.

5. Create a "cognitive dissonance" between the preconception and some observed phenomenon which the preconception cannot explain.
6. Support students' search for a solution and encourage signs for forthcoming accommodation. Encourage elaboration of the new conception when it is proposed.

In the following sections of the paper the ideas presented in the first section and the above proposed guidelines will be applied to the area of teaching the particulate model of gases to students who do not hold a particulate conception of matter. A detailed case study is presented below preceded by an analysis of the relevant cognitive difficulties and the relevant preconceptions known to exist in students.

Cognitive Difficulties in Learning the Particle Model

How do the previous comments apply to learning the particle model of gases? A number of aspects of the model can be identified, each of which implies the necessity for a major cognitive accommodation by the learner. In our view the three most essential aspects of the particle model of gases are: (1) A gas is composed of tiny invisible particles, (2) there is empty space (a vacuum) between the particles, and (3) the tiny particles are moving constantly in straight lines, colliding and bouncing with ideal elasticity. The lessons described later in this paper deal only with the first two of these three aspects of the model. The third

aspect was treated in subsequent lessons not described in the paper.

These three ideas are clearly in conflict with immediate perception acquired from a very early age. Upon these early perceptions children naturally constuct a "naive" alternative framework about the nature of matter -- one that sees it as continuous and basically static. A child's outlook (as well as anyone who has not had formal science instruction) is that there is no place in our immediate surroundings that is completely free of matter. If matter is removed from a given space, then it is immediately filled again by other matter -- in many cases, air. This view is expressed so clearly by the old Aristotalian statement saying that "nature abhores a vacuum (Toulmin, 1962).

In our previous studies (Novick and Nussbaum, 1978, 1981) we have shown that many students, up to high school and even college, claim that air is made of (sometimes they say "contains") invisible particles, while they have not really abandoned their conception of matter as continuous. They will say, for instance, that between the particles in the air there are more particles, bacteria, pollutants, oxygen, etc. or they might say that between the air particles there is simply "more air." When they are asked to draw a 'complete picture' of the inner structure of air they are likely to fill the spaces in between the particles in their drawing until it becomes a continuous picture.

Such students have assimilated new information, namely that air is made of particles, into their own alternative framework of continuous matter ("air contains particles"). By way of analogy, they previously pictured air as transparent jello and now picture it as jello imbedded

with raisin-like particles. They have yet to achieve an accommodation of their alternative framework which would entail a "revolution" in their conceptual understanding of gaseous matter. Similarly, our previous studies have shown that the idea of a constant self motion of the particles is not internalized by many students, even among those who claim that gases are made of particles.

Our previous studies alr- have shown us that a rival conceptions for the particle one emmerge not only from a clear position about the continuity of gasous material but also from a clear positoin about the possible existance and the "nature" of vacuum. Students may make various strong statements like - "'empty space' can't exist" or "vacuum has a sucking force that sucks everything into it." It should be recognized that some kind of a clear position about the notion of "vacuum" must be an integral and an essential element in either the continuous or the particle model of the structure of matter.

Based on the ideas stated above, we have designed a teaching unit on the particle model of gases, composed of some eight to ten lessons. When we approached the application of our previous studies to the designing of introductory lessons of this teaching unit, we looked for the "critical situation" that would serve the purpose of exposing relevant preconceptions in every student. We designed this "critical situation" in a way which would "force" each student to take simultaneously a position with regard to the expected behavior of gas material in an "under pressure" conditions and with regard to the possible existance of "empty space" - vacuum. This "critical situation" was created by the phenomenon

of the partially air evacuated flask.

In the following sections we present a brief explanatory account of the first two lessons of the unit as taught in Israel to seventh grade classes in four Jerusalem area schools, and in two sixth grade classes in Ithaca, New York.

Introducing the Particle Model for Gases - A Case Study

The first two lessons of a longer teaching unit are described below. The development of each lesson is divided into several phases.

Lesson 1 - Exposing Alternative Frameworks and Creating Cognitive Dissonance

Our lesson opens with the presentation of a flask containing air and an evacuating hand pump, whose operation is demonstrated. Learning set is established when pupils feel the pump's sucking effect against their fingers (the laughter generated contributes to a relaxed atmosphere in the classroom).

flask containing air

evacuating pump

Phase 1: "Which part of the flask is left without air?" or "Where do you place the 'empty space' (vacuum) in your model?" — setting a "critical situation."

> "...We would need a much better evacuating pump to take out most of the air from this flask. Let's connect the flask to the pump and push the piston in and out about ten times. Let's assume we've removed half the air from the flask.
>
> Of course, we can't see the air in the flask. Let's pretend that each of us is given a pair of 'magic magnifying spectacles' through which we can actually see air. I want each of you to imagine you're looking at the air in the flask through your 'magic spectacles.' What would you see? I am giving each of you a sheet of paper with two drawings of a flask in outline -- one for the air before we used the pump and one for the air remaining after we removed half of it. I ask each of you to draw the air in the two flasks on the sheet, as it would look through the 'magic spectacles', before and after the partial evacuation."

The teacher, moving around among the working students selects representatives of each type of drawing. Each representative is sent to the chalkboard to reproduce his/her speculated picture of the state of the air in the flask "before" and "after". Several flask outlines were prepared beforehand on the chalkboard by the teacher. Soon we have three to seven different depictions of the air in the evacuated flask, on the chalkboard. All the distinctly different pictures of the air get to be represented. After the various representatives finish to put their imagined pictures of the air on the board they return to their desks and the teacher carefully labels the contributor's name and adds very short description of the drawing. At this point the chalkboard looks like Figure 1 without the "reasons" which are filled in later in the lesson.

	1 David	2 Sara	3 Ruth	4 Gideon	5 Miriam	6 Dan	7 Benny
description	Air remains on the bottom; above it there is a vacuum.	Air fills the flask, but there is less of it.	The air that is left is on the top; below it there is a vacuum.	The air remains near the side-arm.	Most of the air is on the bottom, then less and less and on top - a vacuum.	Air fills the flask, but there is less of it.	The remaining air is in the middle and around it there is a vacuum.
drawings								
before evacuation	after	after	after	after	after	after	after
reasons	The air sinks because its specific gravity is greater than the vacuum.	The gas flows, so the air flows to fill the flask.	Air has nearly no weight; very light things rise.	We pulled the air from this opening; the remaining air concentrates there and wants to push out.	It's like what we learned about the atmosphere in our geography lesson.	This is like the second drawing, but it would look like this if a little dwarf could get in and see.	I can't give a reason; I just feel it should be that way.

Figure 1

Blackboard Array of Pupils' Hypotheses

A few methodological comments are in order here.

1. It is important that all the students draw their imagined pictures simultaneously and be encouraged to do it as independently as they can. The teacher may send to the chalkboard students of average ability or of less vigorous nature in order to pull into the discussion even the more shy, quiet and insecure students.
2. The teacher is adviced to refrain from any hint of value judgement -- all drawings are equally accepted. The teacher may say: "that's interesting"; "here's a new idea." He/she better not say: "good"; "fine", etc.
3. Neat, accurate drawings and descriptions using chalk of different colors definitely help students to differentiate meaningfully between the alternative suggestions, thereby contributing to more active class participation.
4. It is desireable that the teacher will always refer to drawings by the contributor's name -- "who wants to support David's drawing?"; "'who thinks Benny's drawing isn't right?"; "according to Gideon's theory, the air wants to burst out"; "Sarah's theory doesn't show us from where the evacuated air is missing."
5. The class will not always elicit as many as seven hypotheses; more generally one may get four or five. While the teacher should try to encourage many suggestions, it

isn't necessary to belabor the point. We have found that as few as three hypotheses are sufficient as a start toward a very interesing discussion.

Phase 2: "Give reasons for your hypothesis" — deepening awareness of the component of each alternative preconception

> "... Now that we have all these interesting descriptions, I suggest we go back and ask each contributor just why he thinks the air looks like that after we took out half of it with the pump. Anyone else is also welcome to add reasons for the drawing that looks the best to him.

The reasons offered for the drawing are shown in Figure 1, as they appeared on the chalkboard array. During this phase arguments develop in a lively give-and-take atmosphere -- there is a heightening of intellectual tension. We tell the students, however, that we want to concentrate first on reasons supporting each hypothesis and delay counter-arguments for the next phase of the lesson -- the open debate.

> "Now that we clearly understand each of your drawings, we have a problem. We received quite different suggestions from you. Can all of them be correct? Is there one which is more correct than the others? Which one is the most correct? How shall we find out? Shall we take a poll? (Students explain why a democratic poll is not a scientific method.) It is true that a poll is not the right way to find out who's correct. Nevertheless, let's find out how you all feel about this -- just to see 'which way the wind blows'".

By taking a poll, we will of course get a different distribution in

each class, but we have noticed a pattern. In all the classes we have taught, drawings 1, 3, and 4 received the most support. What do they have in common? Well, they all picture the air as one big "chunk" which is found in some defined part of the flask, and where the air was removed (by the pump) a vacuum is left.

Another comment on "atmosphere" is in order here. With this "poll of public opinion" pupils become more involved and very curious to find out who gave the "correct" description.

Phase 3: "Pros and cons" — debating the issue. Sharpening awareness for alternative preconceptions.

> "Well, it seems you're all very eager to find out how the air should really look through our magic magnifying spectacles. We should look at the logic of each position and try to see how it fits with other experiments we could do with air. Now break up into groups and see what you can come up with to defend or refute each of the drawings."

In classes used to working in small groups, the argument is especially lively and sometimes heated. At this point, even the more reticent students become involved. Interestingly enough no critical remarks (pro or con) were made about Dan's drawing (No. 6). Why? It would seem that at this stage, the idea that the air could be in "chunks", with empty spaces between them, is so foreign that no need is felt to argue against it.

At the conclusion of Phase 3, after students have had a chance to give considerable thought to the problem of where the vacuum exists in the evacuated flask, we judge that all the students in the class have become aware of their own conceptions by presenting them laoudly and by confronting other conceptions of their peers. This confrontation, we

believe, introduces in the students the seeds for a state of "disequilibrium" or "cognitive dissonance" that will mainly build up later in the lessons. We are now ready for the next phase.

Phase 4: "What makes air compressible?" — preconceptions get into a "dissonance" with a reexamined phenomenon

Our first lesson ends with the demonstration of a phenomenon that will hopefully lead to an accommodation in students' cognitive structures -- that is, get them to see the need for the existence of empty space in any sample of air (or other gas).

> "Let's leave our "hot debate" for a moment. I'd like you to recall what we found out about compressing gases, liquids and solids. Let's compress some air in this syringe... (demonstration)...You all remember that we couldn't compress a liquid or a solid like that. I wonder — does compressing a gas like this raise any questions for you...does it make you wonder...?"

Either on their own initiative or with some help from the teacher, students arrive at the following query:

> How can you force one half of the air, which is in the cylinder, into the remaining space which is already occupied by air?

> "After all, we know from everyday experience with things that aren't gases that you can't take their place without moving them away (two pupils can't sit at the same time on the same seat). So how does the air in the bottom of the syringe allow more air to occupy the same space when we push down the plunger?"

> What in the nature and the structure of air

makes it so compressable?

"We've come to the end of our lesson today. Shall we continue with this problem next time? (A chorus of assent.) OK. Then think about it until tomorrow. I suggest you try to see which of the drawings on the chalkboard could help you to best explain how we can compress air in a syringe."

Lesson 2. Cognitive Dissonance Leads to Accommodation and the Invention of a New Model.

Our second lesson begins with a review of the various descriptions of the air left in the flask, with the help of dittoed sheets showing the blackboard array of descriptions, drawings and reasons (see Figure 1).

"Let's go back now to our discussion about air in a syringe, which I hope you've thought about since our last lesson. Here you see how I can easily make 100 cc. of air occupy only 50 cc. (teacher demonstrates). What questions can be asked about this peculiar phenomenon?"

Students talk about this in small groups or in class discussion and the following three questions emerge on the chalkboard.

How can two quantities of air in the syringe, each occupying 50 cc. (together, 100 cc.) occupy only 50 cc. after the plunger is pushed in?

Why can this be done only with a gas, like air, and not with a liquid or a solid?

What is special about the structure of air that allows it to be compressed?

"Now, as you remember, I asked you at the end of our last lesson to think about which of the seven descriptions of the air in the evacuated flask might help us to answer these questions."

Students begin to search for some relationship among the various

speculated "structures," represented by the drawings, and the observation of a phenomenon unique to gases: their compressibility. The kinds of responses offered will of course vary from group to group. However, in every class that we have taught, at least one student suggests something to the effect that,

> "Maybe air is always like Dan's drawing (number 6) -- even when we don't remove any of it. Maybe air is made of little pieces with empty space in between."

In one case one of the students suggested this model (basically not too different from a particle model):

> "Maybe air is like a sponge. Maybe the air is like the sponge material itself and between the chunks of air there is empty space like the holes in the sponge."

The discussion now becomes very lively; students are personally very involved in the debate. They try to show how their own drawings could explain the air's compressibility and to deal with the criticism of their classmates. Students are seen using paper and pencil and hand gestures to help their arguments pro their picture of air structure and behavior in the flask and in the syringe. We have found that the suggestion that Drawing 6 explains the air's compressibility is at first rejected by many students. For them the idea that there is a 'vacuum' in ordinary air is just too strange. The teacher, while refraining from expressing preference for any one drawing, presses the 'anti-particle' students to offer a better explanation of the air's compressibility. Most pupils begin to realize that despite the strangeness of the "particles in a vacuum" idea, it does explain both phenomena -- the evacuation and the compression of air. More and more students join the "particle camp" and even volunteer to argue against their previous opinions.

One argument against the particle idea should be noted. Some students said,

> "If we assume there is empty space among particles, then why doen't water rise into a glass of air inverted in a bowl of water?"
>
> "What holds the particles separated from each other if there is just empty space between them? Why don't the particle just fall down and pile up at the bottom of the flask?"

The teacher acknowledges these questions and even writes them on the chalkboard as good questions to be kept in mind. These responses show the need to introduce inherent motion of particles as part of the model, to explain pressure phenomena. This additional aspect is developed in subsequent lessons by invoking again "cognitive dissonance" and accommodation.

After the particle picture has become the focus of discussion and its supporters are increasing, the teacher intervenes to demonstrate the compression once again, but this time compressing 100 cc. of air to just 20 cc (5 il).

> "If we assume the air is really composed of particles, what does this compression suggest about the amount of space taken up by the particles compared with the empty space between them?"

Students suggest the empty space is much larger than the space taken up by the particles

> "If I had pressed much harder on the plunger, I could have compressed the air even more. But even if we used a steel

> syringe and exerted tremendous force, we still couldn't compress the air to zero volume. We always reach a minimum volume. Why?"

Students suggest that the limit of compression is reached when there is no more empty space between the particles.

Our second lesson ends with the teacher's statement:

> "Indeed the picture scientists have accepted is that of air composed of particles and empty space among them. The question which now arises is why the air resists being compressed — Why do we have to press on the plunger to keep the air compressed? We'll talk about this problem next time."

Concluding Comments

We feel that the lessons described above contribute to the students' conceptual change (accommodation) in the following ways:

They became aware of the elements in their own alternative frameworks for the "structure of air."

They personally feel the need for a theoretical model of the "structure of air" which includes empty space in some way or another.

They engage in a meaningful discussion of competing hypothetical models.

They experience "cognitive dissonance" which lends to accommodation.

Two teachers who observed our lessons and later taught themselves offered these comments:

> "I have taught the particle model for many years now and this is the first time all my students showed interest and enthusiasm. After these lessons they continued to wonder about the structure of air and came on their own during recesses to talk about it. They wanted to know more about

> the 'correct' description and asked about new arguments they had thought of in the meantime."
>
> "My pupils felt good about the fact that theories about the structure of air were their own. When they came to accept the particle idea it was theirs and not merely a statement in a book."
>
> "These lessons created very strong motivation for all the lessons on the particle model that followed."

We believe that the case study described in this paper may serve as a good example of employment of research findings about students' alternative conceptions in the development of teaching strategies for initiating a conceptual change. More examples like this one are urgently needed in science teaching and we hope that our attempt in this case study will stimulate other science eductors to follow with other examples.

The authors are presently conducting a project, at The Hebrew University of Jerusalem-Israel, in which this case study (hopefully followed by similar ones) is used as a source for pre and in-service teacher training. This is done through teachers observing and analyzing of videotapes of lessons from the case study supplemented with theoretical readings and exercises in designing other similar cases.

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